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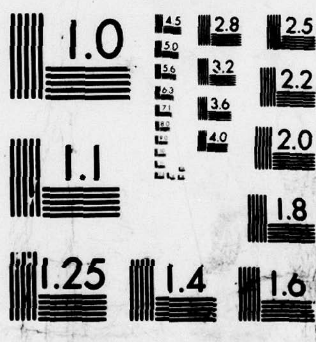

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LEVEL II

EFFECT OF PERIPHERALLY PRESENTED VISUAL SIGNALS ON PILOT PERFORMANCE DURING FLIGHT SIMULATION

JOHN M. BERMUDEZ, MAJOR, USAF
JOCK C. H. SCHWANK, LT. COL., USAF
THOMAS M. LONGRIDGE, JR., CAPT., USAF
BRUCE A. SMITH, CAPT., USAF
THOMAS M. McCLOY, CAPT., USAF

DEPARTMENT OF BEHAVIORAL SCIENCES AND LEADERSHIP
UNITED STATES AIR FORCE ACADEMY, COLORADO 80840

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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
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Recent theoretical developments have stimulated interest in the development and testing of peripheral vision displays which could be used to monitor the control of aircraft attitude. This study investigated the ability of pilots to attend to peripherally presented attitude information via LED displays while simultaneously engaging in foveal processing of an instrument array during a complex maneuver in a flight simulator. (over)

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Twenty-four pilots were divided into two groups of twelve. One group performed vertical S maneuvers using an LED display that indicated an out-of-tolerance condition in compass heading (steady LED). The second group used an LED that provided both out-of-tolerance information and rate-of-error information (strobe LED). All pilots were pre-trained to criterion. Both groups performed under each of three display conditions: Normal (standard round compass dial), Redundant (dial and LED), and Peripheral (LEDs-only). Analysis of compass errors yielded significance for type of display ($p < .05$). Compass errors were greater with the round dial, whereas the LED-only display produced fewer errors; however, differences in means were not practically large. Analyses of overcorrections of compass errors were also significant for type of display ($p < .001$), and differences in means were substantial. Correlations between errors and overcorrections for each of the three conditions were reliable and accounted for most of the variance ($r = -.73, -.76, -.84$; $n = 24$; $\alpha = .001$, respectively). There were no statistically significant differences between the steady LED display and the strobing LED display. Overall, the results suggest that peripheral displays are at least as effective as compass dials for monitoring purposes, and such displays might prove useful as adjunct training aids with the potential for improving safety.

PREFACE

The research reported herein was funded by the Visual Display Systems Branch, Human Engineering Division of the Aerospace Medical Research Laboratory, as part of Project 7184 11 (Project Order AMD/RDO 78-1) to the Department of Behavioral Sciences and Leadership, U.S. Air Force Academy, Colorado. This report covers research performed between October 1977 and September 1978 and serves as the final technical report under the Project Order.

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INTRODUCTION

The aim of this long-term research project is to advance the state-of-the-art by applying psychological and human factors engineering knowledge to the improvement of flight control monitoring devices. The Aerospace Medical Division, AMRL, through the Department of Behavioral Sciences and Leadership, U. S. Air Force Academy, is conducting a series of experiments designed to test recent theoretical developments concerning information processing characteristics of human vision and attention. The primary purpose of these experiments is to gather empirical data on the effectiveness of presenting flight control monitoring information for viewing in the extreme visual periphery.

This report, the first in a series, presents data gathered in a dynamic flight environment using a Singer-Link General Aviation Trainer (GAT-1) simulator. Specifically, the present experiment was an initial examination of the feasibility of using peripheral vision indicators to monitor aircraft heading during a complex instrument flight maneuver. Subsequent reports will cover various effects of psychological stress on peripheral vision processing, estimates of the validity and reliability of explicit training to improve peripheral processing ability, and the role of individual differences in peripheral vision processing.

Recently, several authors have provided evidence that peripheral vision is monitored at a pre- or non-conscious level by the midbrain (Ingle, 1967; Schneider, 1967; Trevarthen, 1968; Held, 1968; Leibowitz and Dichgans, 1977), providing the viewer with visual information that is useful for determining spatial-postural orientation. This type of processing has been referred to as ambient vision (Leibowitz and Dichgans, 1977). Because ambient vision is controlled by the midbrain, bypassing conscious awareness, it is logical to suppose that it is resistant to psychological stress. A second mode of vision, referred to as focal vision, localized in the foveal region of the retina, is controlled primarily by the cerebral cortex and is associated with

conscious attention to details in the visual environment (Leibowitz and Dichgans, 1977). Under some conditions this type of vision has been found to deteriorate under stress (Leibowitz, 1973).

A hypothesized stress-resistant property of ambient vision would appear to be most probable when task demands require orienting to and detecting motion, especially since it is known that the neurons in the retinal periphery are excellent rate processors (Ener, 1974). Consequently, it may be possible for a pilot to be engaged in focal processing during a complex flight maneuver while simultaneously and effectively attending to peripherally presented aircraft attitude information in the form of apparent motion. Moreover, it appears that peripheral vision is trainable (Johnson and Leibowitz, 1974). Examples of information that could be processed peripherally include compass heading errors, pitch errors, or roll errors where change of rate in the peripheral signal is yoked to extent of error. If such peripheral vision motion cues are effective orientation indicators, one would expect pilots to benefit by their use in relatively stressful flight situations (e.g., formation flying, landing, and acrobatic or evasive maneuvers) where the peripherally presented signals might offer better aircraft control than would be possible with normal instruments.

METHOD

SUBJECTS

Pilots were randomly and independently selected from a pool of Air Force Academy Cadets who volunteered to participate. Twenty-four males between the ages of 19 and 24 were employed. All pilots had completed 18-24 hours of flight training in the T-41 aircraft within the preceding six months, and none had yet obtained a commercial license. This training included one solo flight. The pilots were randomly assigned to one of two experimental groups, with 12 pilots per group.

DESIGN

A diagram of the experimental design is presented below.

	Type Display		
Type Signal	Normal Heading (Dial Instrument)	Redundant (Both Dial and Light)	(Light Signal)
	S_1	S_1	S_1
Strobe Light	.	.	.
	.	.	.
	.	.	.
	S_{12}	S_{12}	S_{12}
	S_{13}	S_{13}	S_{13}
Steady Light	.	.	.
	.	.	.
	.	.	.
	S_{24}	S_{24}	S_{24}

One factor, type of visual signal (TS), provided two between-subject experimental groups. Type of display (TD) was treated as a within-subject variable. The resulting design was a 2TS (strobe light vs steady light) × 3TD (heading instrument vs peripheral light vs heading instrument plus peripheral light) mixed analysis of variance with repeated measures on the TD factor.

APPARATUS

Training and experimental sessions were conducted using a Singer-Link GAT-1 Simulator, Model 633000. This aircraft simulator provides the same primary instrument display as the T-41 aircraft (heading indicator, airspeed indicator, vertical velocity indicator, altitude indicator, attitude indicator, and tachometer). Cockpit design and simulated flight characteristics are also highly similar to the T-41.

Two types of peripheral vision signals were used. Both signals were mounted bilaterally on an adjustable faceplate. One signal (strobe light) consisted of five light emitting diodes (LEDs), green in color, wired in series. Each LED was 2.4 mm in diameter. The five LEDs were placed 6 mm apart in a vertical line. This visual display yielded a downward strobe of light which was rate-yoked to heading deviation. Onset of the light occurred only when the pilot exceeded the desired heading by ±1 degree. The strobe signal was positioned such that the center LED of the five-light sequence crossed the horizontal meridian (0°) of the nasal retina at 55 degrees of eccentricity from the fovea when the pilot fixated a point along his normal viewing axis at a distance of three meters. Total visual angle subtended by the vertically placed LEDs was 14.5 degrees. The other signal (steady light) consisted of a single green LED mounted in the same fashion along the horizontal meridian at 55 degrees of eccentricity which subtended a visual angle of 2.0 degrees. Presentation of either visual signal was unilateral, left or right, whenever heading was out of tolerance by more than one degree. The LED display functioned as a command indicator. In order to terminate it and thus null an error signal, the pilot was required to make a heading correction toward the side on which the visual stimulation was presented. In other words, a downward strobe of LEDs on the right side indicated that the pilot should turn the control wheel downward to the right. The indicated heading correction was compatible with the required response.

PROCEDURE

TRAINING

All pilots were provided with training to criterion on a vertical S maneuver for one hour. The training criterion consisted of performing the vertical S maneuver without deviating more than 10 degrees from the desired heading. The type of vertical S maneuver utilized consisted of alternately climbing and descending 250 feet (76.2 m) above and below a baseline altitude of 2000 feet (609.6 m). Subjects were required to maintain a fixed airspeed of 80 mph (35.75 m/sec) and a fixed heading of 270 degrees, and to establish a fixed vertical velocity of 500 fpm (2.54 m/sec).

All pilots were required to meet the training criterion using each of the three types of displays: Normal (using the compass dial without LED display); Redundant (using the compass dial plus one of the peripheral LED displays); and Peripheral (using one of the LED displays with compass dial occluded).

EXPERIMENT

For any given pilot, the experimental session occurred on the second day following training. The faceplate with mounted peripheral vision displays was adjusted for the desired retinal projection at 55 degrees of arc subtense from the fovea. The pilot was then seated in the GAT-1 and was allowed a 6-minute practice session, during which he performed one vertical S maneuver under each of the three display conditions. The order of conditions during practice was counterbalanced across pilots and coincided with the order given during test trials. The pilot performed the maneuver twice under each of the three test trial conditions.

Four minutes of rest in the GAT-1 was allowed between each display condition. Dependent variables were recorded continuously using a strip chart recorder. These included deviation in degrees from desired compass heading, errors in airspeed, errors in vertical velocity, and frequency of heading overcorrections. Overcorrections were defined as swings in heading from one side of the desired heading of 270 degrees to the other side of the desired heading (e.g., 273° to 268°).

RESULTS AND DISCUSSION

A perfectly performed vertical S maneuver would last exactly two minutes. Since each pilot performed two maneuvers per display condition, each pilot yielded approximately four minutes of test trail data per condition. All data subjected to analyses were taken from the middle 200 seconds of each 4-minute interval. Discrete measures of the pilot's ability to maintain a constant airspeed (80 mph, 35.75m/sec) and compass heading (270°) were taken at 5-second intervals. Absolute deviations from these standards were then

averaged for each pilot. In addition, the total number of heading overcorrections was tabulated for each pilot. The ability of the pilot to maintain a constant rate of climb and descent (500 fpm/2.54 m/sec) was measured from a point at which the standard rate was initially established during climb or descent until the reverse direction was initiated. As with heading and airspeed, vertical velocity and altitude were sampled at five-second intervals and mean absolute deviations were computed.

Table 1 presents the means and standard deviations of compass heading errors. A 2TS (type signal) × 3TD (type display) ANOVA on heading errors yielded significant main effects only for TD ($F = 3.77$, $df = 2/44$, $p < .05$). Comparisons of the means showed that subjects using the standard round dial compass, the normal condition, made siginificantly ($\alpha = .001$) more compass heading errors than those in the redundant condition. No other comparisons of heading errors reached significance.

The means for all six conditions are portrayed in Figure 1. In the normal condition, both groups of subjects used the same standard aircraft heading round dial instrument. As indicated in Figure 1, there was virtually no difference between the two groups in this control condition. However, the two groups varied considerably (but not significantly) in their ability to control aircraft heading when the only heading reference was from the peripheral indicators.

TABLE 1

MEANS AND STANDARD DEVIATIONS IN AVERAGE DEGREES OF ERROR IN COMPASS HEADING PER 200 SECONDS OF SIMULATED FLIGHT

TYPE OF DISPLAY

Type of Signal	Normal(control)[a] Error	Redundant[b] Error	Peripheral[c] Error
Strobe M	3.99	3.36	3.85
Group SD	1.50	1.55	2.08
Steady M	3.97	3.15	2.89
Group SD	1.88	1.30	1.17

a. The normal condition was flown using the standard round dial compass.

b. The redundant condition was flown using the standard round dial compass concurrently with the peripheral indicators.

c. The peripheral condition was flown without the use of the normal round dial compass.

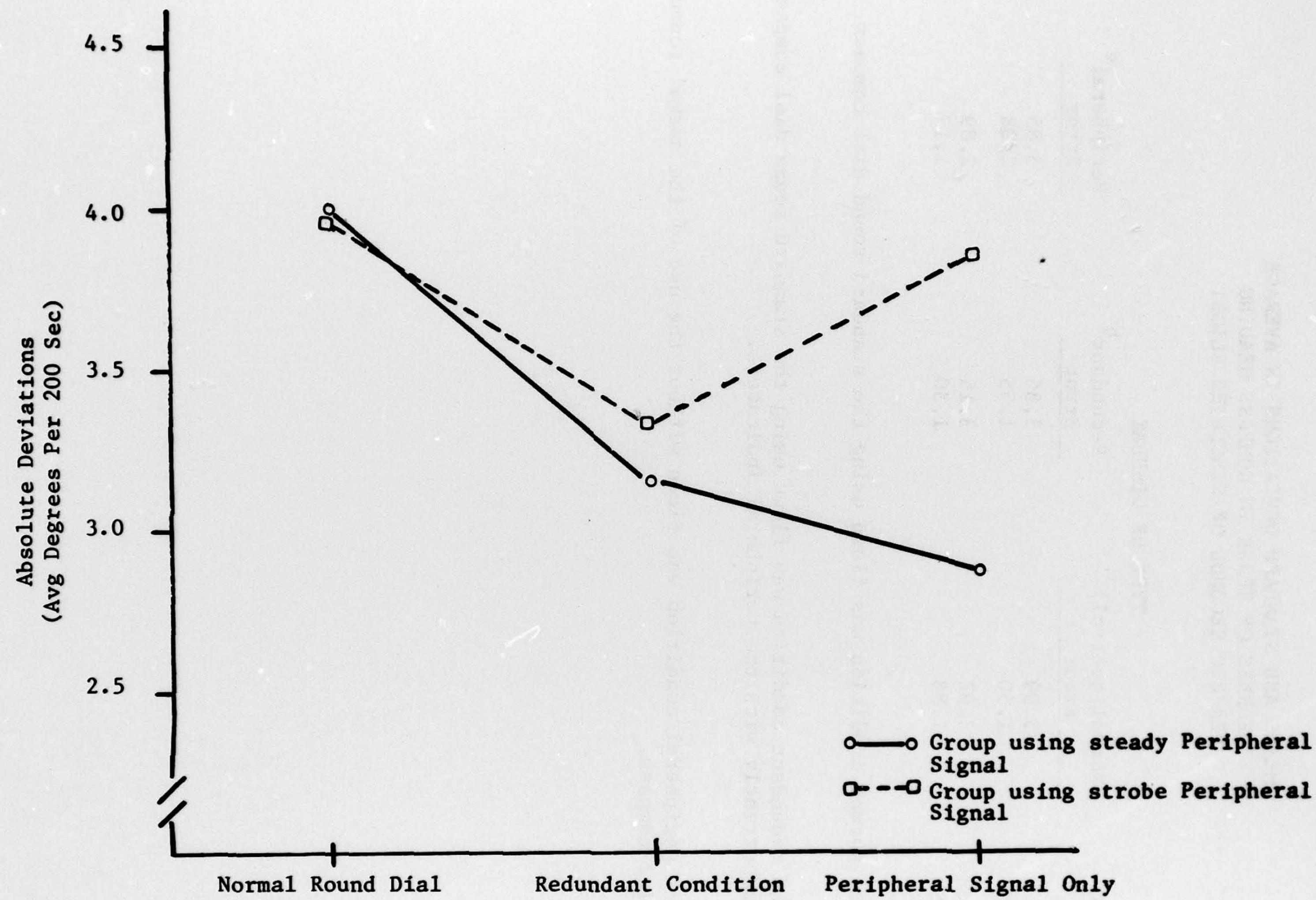

Figure 1. Absolute Heading Deviations for Three Sources of Heading Information

TABLE 2

MEANS AND STANDARD DEVIATIONS IN
AVERAGE NUMBER OF OVERCORRECTIONS PER
200 SECONDS OF SIMULATED FLIGHT

TYPE OF DISPLAY

Type of Signal	Normal (control)[a] Overcorrects	Redundant[b] Overcorrects	Peripheral[c] Overcorrects
Strobe M	12.50	18.00	20.08
Group SD	9.73	11.09	10.27
Steady M	12.00	18.33	22.58
Group SD	5.04	5.08	8.32

a. The normal condition was flown using the standard round dial compass.

b. The redundant condition was flown using the standard round dial compass concurrently with the peripheral indicators.

c. The peripheral condition was flown without the use of the normal round dial compass.

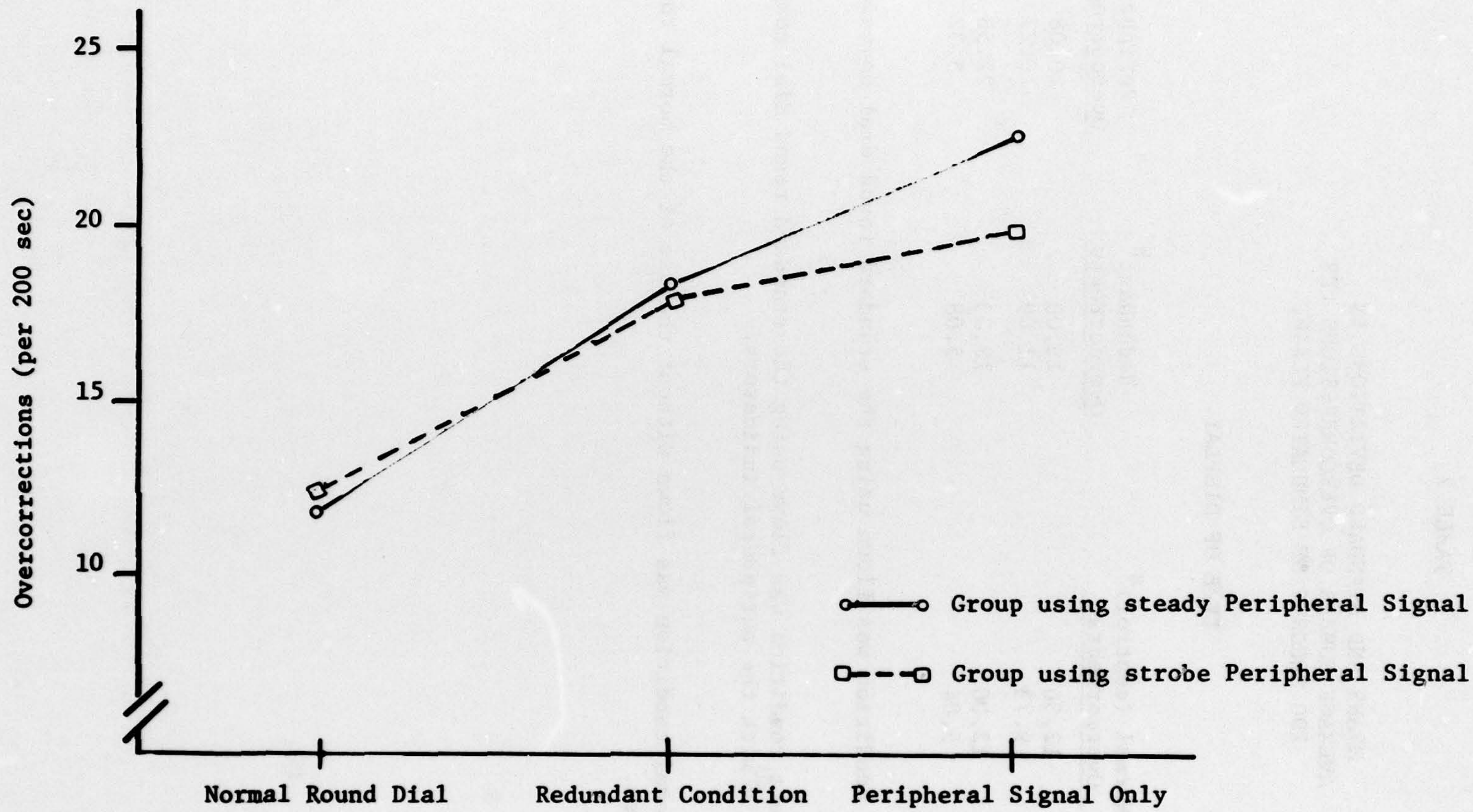

Figure 2. Heading Overcorrections for Three Sources of Heading Information

One of the goals of this study was to find potential indices which would assess the pilot's performance. Pearson product-moment correlations between absolute heading deviations and heading overcorrections appear to provide such an index, and in the present study, this index is most evident when the data are collapsed across type of peripheral display and correlated by display condition. An important result, therefore, concerns the decreasing number of compass heading errors in relation to the increasing number of overcorrections. As the coefficient of this inverse correlation increases, the pilot is making more heading overcorrections and/or deviating less from the desired heading. Pearson product-moment correlations between error scores on compass heading and heading overcorrections for the normal, redundant, and peripheral display conditions were $r = -.73, -.76, -.84$, respectively, ($N = 24$, $\alpha = .001$ for each case). It was determined that the variance accounted for (r^2) increases reliably across the three conditions.

Although the differences in compass error means as shown in Table 1 and Figure 1 were statistically significant among display conditions, they do not appear to attain practical significance. However, there do appear to be large practical differences in the number of overcorrections, indicating that pilots attended more closely when the peripheral display was the source of heading information. If one makes the assumption that overcorrections are desirable when the information processing requirement involves monitoring and responding to deviations in a flight parameter, then the results tabulated in Tables 1 and 2 and depicted in Figure 1 and 2 suggest that peripheral vision displays are superior to compass dials.

None of the analyses produced statistical main effects for differences between the two types of peripheral signals. In view of the relative superiority of peripheral vision for motion detection, it was somewhat surprising that the strobing signal (providing rate-yoked information) was not more effective than the steady peripheral signal (which gave only on-off information). Based on these data, however, it would seem that the ambient vision system is no more effective in processing rate information than

in processing changed-state information. At this point in the research effort, the reason for this lack of difference is unclear. It may be that the pilot is task-loaded to the point where he has limited capacity to process the rate information and finds it equally efficient to use only changed state information in this monitoring task.

On the present evidence, it seems justifiable to hypothesize that the relative advantage of using a peripheral display to supplement or replace the normal, round dial display stems from the continuous feedback available in the visual periphery. For example, in the present experiment, a peripheral signal provided both prompting and feedback. In the redundant condition, the peripheral signal may have functioned mainly as a prompt, making it unnecessary for the subject to constantly scan the compass dial. Since, under these circumstances, he needed to foveate on that instrument and confirm its extent of error only when it was out of tolerance, he, therefore, had more time available for scanning other instruments. Thus, the availability of peripheral cues made it possible for the pilot to reduce heading deviations without degrading his performance on other aircraft control parameters. This interpretation tends to be in agreement with the present data which show no differences among the three display conditions regarding their effects on the maintenance of required airspeed and vertical velocity.

From a training standpoint, it would seem that a peripheral signalling device would offer two distinct advantages. First, it acts as an adjunct training aid providing a continuous flow of information to the novice pilot, giving him feedback in the context of a trial-and-error situation. As an example, training instrument approaches such as VOR or ILS would lend itself to this type of cueing as the pilot is learning to integrate new information with established instrument scanning patterns. It has also been shown repeatedly that the method of trial-and-error with feedback is a preferred method of training complex perceptual tasks (Prather, Berry, and Bermudez, 1972). Secondly, it is probable that a peripherally mounted device would provide increased safety, given that peripheral displays are effective in cueing pilots to out-of-tolerance conditions. Therefore, in environments like air-to-ground gunnery training, it is possible that

pilot safety could be enhanced by providing additional altitude cues in the visual periphery.

The present data also suggest the possibility of developing a performance measure which may have utility for several situations. Such a measure could be used for training evaluation, crew workload measurement, and for developing crew station design criteria. In the current experiment, this measure is simply the ratio of mean heading deviation errors to overcorrections. This ratio may provide two simple and useful indications of performance related either to equipment performance or to personnel performance. Generally, it can be assumed that the smaller the ratio, the greater the effectiveness of an instrument, or the greater the responsiveness of the operator. Since the Effectiveness/Responsiveness Index (E/RI) is also insensitive to the unit of measurement used, it could have wide application. For example, it can be assumed that the effectiveness of a signaling device is indicated by the responsiveness of an operator to null the signal. Alternatively, the level of skill or level of attention of an operator is indicated by the responsiveness of the operator to perform the same action. Since several flight controls and parameters are very sensitive to pressure and movement, trainees, as well as experienced pilots, are apt to make overcorrections in responding to the signal. Therefore, such an index might prove useful to trainers, researchers, and design engineers.

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